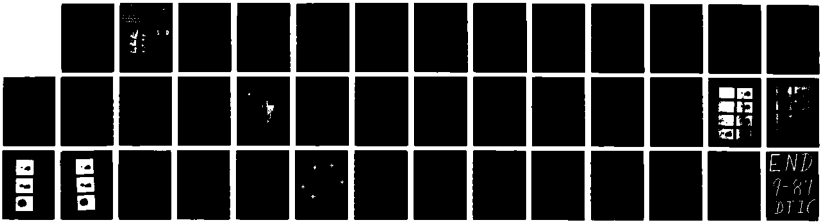
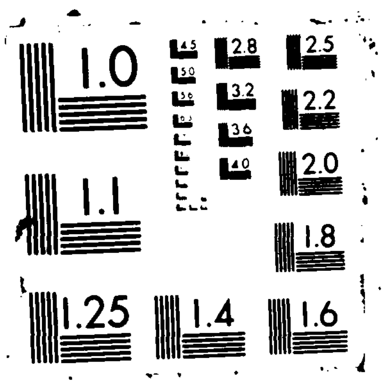
AD-A183 769 SMOKE MANAGEMENT FOR NAVAL SURFACE SHIPS(U) ASSOCIATION OF SCIENTISTS AND ENGINEERS OF THE NAVAL SEA SYSTEMS COMMAND WASHINGTON DC T G LAVALLE ET AL. 03 APR 87 1/1

UNCLASSIFIED F/G 13/12 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

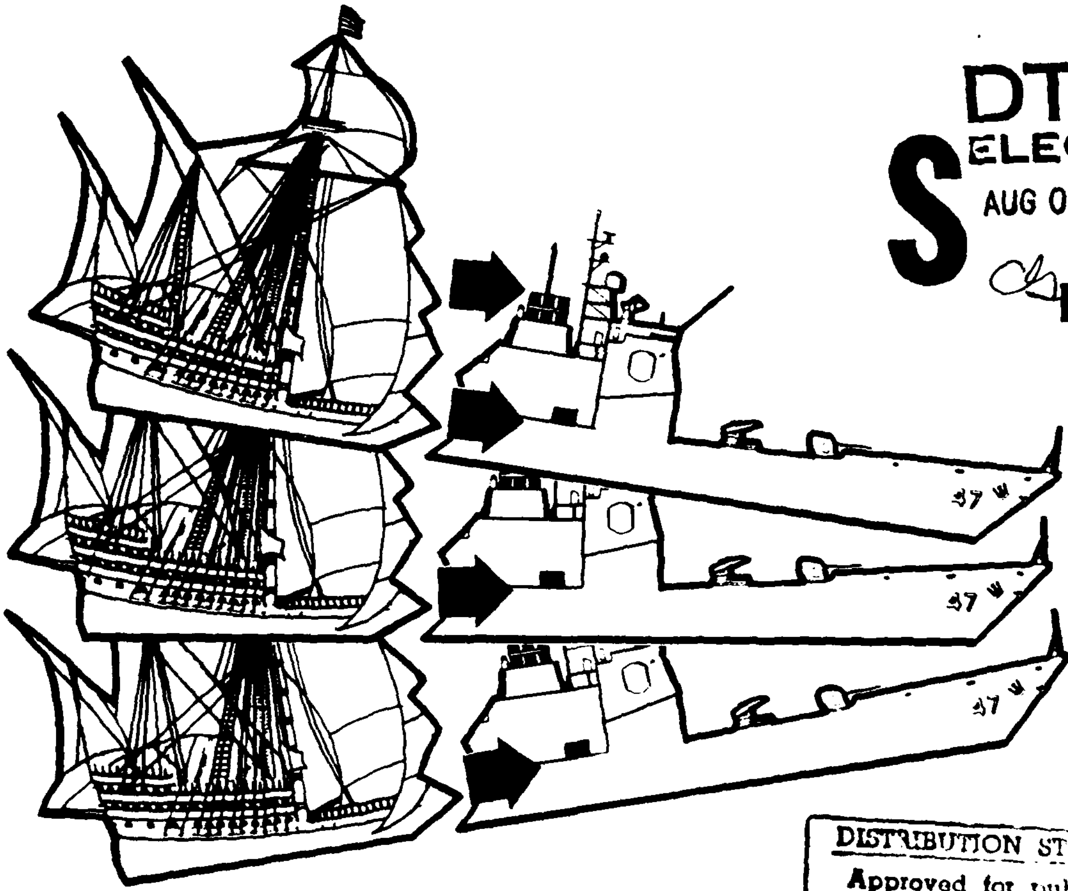
DTIC FILE COPY

24TH ANNUAL TECHNICAL SYMPOSIUM 1987

"NAVY IN THE NINETIES — TREND AND TECHNOLOGY"

AD-A183 769

DTIC
S ELECTE D
AUG 0 5 1987
D



DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

SMOKE MANAGEMENT

by: Tim LaValle, Paul Lain, and Richard Carey

ASSOCIATION OF SCIENTISTS AND ENGINEERS OF THE NAVAL SEA SYSTEMS COMMAND • DEPARTMENT OF THE NAVY • WASHINGTON, D.C. 2036[illegible]

87 8 4 065

SMOKE MANAGEMENT FOR NAVAL SURFACE SHIPS

Richard B. Carey
Chemical Engineer
Ship Materials Engineering Department
Code 2833
David Taylor Naval Ship Research and Development Center

Paul W. Lain
Fire Protection Engineer
Fire Protection Division
SEA 56Y52
Naval Sea Systems Command

Timothy G. LaValle
Mechanical Engineer
Life Support Division
SEA 56Y11
Naval Sea Systems Command

April 3, 1987

ABSTRACT

Smoke is a threat to the lives of personnel and the mission of Naval surface ships. This paper presents a trilogy of smoke management systems and techniques for Navy ships. First, for existing ships, Smoke Containment and Removal Diagrams to assist the crew in rapid containment of smoke during fire and subsequent removal of smoke on extinguishment of the fire are presented. Next, the affect on tenability when ventilation patterns are altered according to the current Main Machinery Space Fire Fighting Doctrine is discussed. Finally, for new construction ships and ships with collective protection systems for defense against chemical and biological warfare agents, integration of smoke management techniques with ship heating, ventilating and air conditioning systems to form a Smoke Ejection System is described.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ADMIN	administrative
AL	Alabama
AT	airtight
AUX	auxiliary
BATT	battery
BHD	bulkhead
BOSN	boatswain
BR	bridge
CA	California
cfm	cubic feet per minute
CHEM	chemical
CHG	charging
CIC	combat information center
CIWS	close-in weapons system
CLNG	cleaning
CO	Commanding Officer, carbon monoxide
COMM	communications
COMP	compressor
CPO	Chief Petty Officer
CPS	collective protection system
CSER	communications support equipment room
CTR	center
DC	damage control
DECON	decontamination
DEF	defense
DEG	degaussing
DH	department head
DK	deck
DTNSRDC	David Taylor Naval Ship Research and Development Center
EH	exhaust high
ELEC	electrical
ELEX	electronic
EO	exhaust off
EQPT	equipment
ES	exhaust system
EXEC OFF	Executive Officer
F	fahrenheit
FLAM	flammable
FR	frame
ft	feet
FT	fume tight
FZ	fire zone
GEN	general
gpm	gallons per minute
HDLG	handling
HVAC	heating, ventilating air conditioning
ISS	issue
LAB	laboratory
LIQ	liquid
LVL	level

MCHRY	machinery
min	minute
MN	main
Mw	megawatt
NAVSEA	Naval Sea Systems Command
NO.	number
OFF	office
OPS	operations
OT	oil tight
PASS	passage
%	percent
PL	platform
ppm	parts per million
PROV	provision
PWR	power
PZ	pressure zone
R/C	rate of air exchange
RDR	radar
REFR	refrigeration
REP	repair
RM	room
RS	recirculation system
SATGCS	Smoke and Toxic Gas Control System
SCRD	Smoke Control Removal Diagrams
SCZ	smoke control zone
SD	supply department
SEC	second
SES	Smoke Ejection System
SF_6	sulfur hexafloride
SH	supply high
SHR	shower
SL	supply low
SNAP	shipboard non-tactical automated data processing
SO	supply off
SPLY	supply
SPRT	support
sq ft	square feet
SR	stateroom
SS	supply system, superstructure
STA	station
STRM	store room
STRS	stores
STWG	stowage
TBD	to be determined
TECH	technical
TRK	trunk
US	United States
WR	wardroom
WT	watertight
XTMR	transmitter
1st	first
2nd	second
3rd	third

INTRODUCTION

The historically catastrophic nature of shipboard fires at sea has long stimulated the interest of both seafarers and ship designers. However, inherent difficulties of containing fire on board a ship have never been overcome and the shipboard fire remains one of the most dreaded occurrences. Smoke generated by a shipboard fire presents a major hazard to the personnel and mission of the combatant ship. Most deaths result when sailors lost in the obscuring smoke cloud inhale the toxic combustion products. Extended damage to or loss of ship may result when sailors hesitate on entering obscured areas or become lost and can not locate the seat of the fire.

In a recent fire on board the USS TATTNALL DDG 19, smoke spread from the involved space rapidly, and forced the aft-half of the ship including two machinery spaces to be evacuated. Extensive electronic damage resulted from the fire. A fire on the USS RANGER (CV 61) resulted in the deaths of six (6) men from toxic gases. In the Falkland Islands conflict rapid spread of smoke on board the British ship HMS SHEFFIELD negated her fire fighting capabilities resulting in her sinking. These and numerous other fires clearly demonstrate the need for effectively controlling the spread of smoke on Navy ships. In 1981, the David Taylor Naval Ship Research and Development Center with the support of the Naval Sea Systems Command launched the first program dedicated to the management of smoke on board Navy ships. This paper presents a trilogy - Smoke Removal Diagrams and Procedures, New Machinery Space Fire Fighting Doctrine Tests, Smoke Ejection System of these efforts. Other efforts to address smoke ingestion, existing ship smoke management upgrade and related problems are underway.

SMOKE CONTAINMENT AND REMOVAL DIAGRAMS

INTRODUCTION

The lessons learned from the USS TATTNALL fire illustrate the hazards of uncontrollable smoke spread. The reports concerning the fire, specified the need to develop specific measures for controlling the spread of smoke during a fire. There are many smoke migration routes inherent in current naval ship design. The ability to identify these routes quickly and accurately will improve our ships fire fighting capabilities.

Compartment segregation is helpful in reducing the area of smoke involvement. There is more compartment segregation below flooding water levels (FWL), (V Lines) than above because of the flood control requirements imposed on accesses, ventilation systems, and bulkhead tightness criteria. Consequently, it is easier to contain smoke below the FWL than above these levels.

A requirement imposed on the ventilation system below the FWL is that no transverse subdivisions, nor individual watertight (WT) compartments within a WT subdivision, be interconnected. Also, WT closures are required on ducting which passes through a WT bulkhead below those levels. These requirements help limit smoke migration.

Below the FWL, the majority of the bulkheads and decks are WT. Bulkheads and decks which are non-tight (NT) are surrounded by other WT bulkheads or decks, thereby, forming a larger WT envelope. Ducting, cableways and accesses which breach WT boundaries are also of WT classification, making smoke migration through the structural difficult.

While horizontal smoke spread below the FWL is difficult, it is possible. As long as the vertical ducting is run WT below the FWL, closures are not necessary. Once the vertical duct run ascends above the FWL, it may run horizontal through a WT or main transverse bulkhead without requiring a closure. The ducting may then descend below the FWL and serve other compartments, provided that they are in the same fire zone (FZ). A single fan located above the FWL, can and often does, simultaneously serve watertight compartments in more than one main transverse subdivision. This is done to avoid the cost, weight, space and complexity resulting from a larger number of smaller systems. The penalty, however, is a potential smoke migration route between compartments and main transverse subdivisions.

Above the FWL, there are few restrictions imposed on the ventilation system which limit smoke migration except for smoke control dampers in duct work serving some, but not all, manned vital spaces. Since flood control is generally not a concern and vital space boundaries are only classified air tight (AT), ducting may penetrate bulkheads without requiring a closure. Also, longitudinal and transverse passageways within fire zones are used as natural air returns. This makes it difficult to segregate areas of smoke involvement.

Bulkhead tightness requirements above the bulkhead deck are not as stringent as those below. There can be main transverse bulkheads that are classified as non-tight (NT), and in some cases, can even have open arches rather than doors for access. A bulkhead of NT classification reduces appreciatively the smoke containment capability when compared to watertight or AT bulkheads.

To contain smoke, fire fighting and damage control personnel must be aware of all possible smoke migration routes. Damage control and fire fighting parties are thoroughly trained and constantly drilled in fire fighting practices. The emphasis of their training, however, is in combating fire not containing smoke. The repair parties priority is to find and extinguish the fire. Actions required to contain smoke may be overlooked.

SMOKE CONTAINMENT AND REMOVAL DIAGRAMS

Smoke Containment and Removal Diagrams (SCRD) are procedures to aid damage control and fire fighting personnel in the containment and removal of smoke. Damage control and repair party operating procedures, ventilation system distribution and bulkhead integrity were evaluated in developing the diagrams. The SCRD allows damage control and fire fighting personnel to quickly identify the area of smoke involvement and gives them the pre-engineered procedures for securing that area's boundaries for smoke containment. The diagrams also provide procedures for smoke removal after the fire has been extinguished.

The concept of the smoke control zone (SCZ) was used in developing the Smoke Containment and Removal Diagrams. A SCZ can be defined as the smallest possible area where smoke can be effectively contained and subsequently removed upon fire extinction. The SCZ defines the area of potential smoke involvement, resulting from a fire originating in any compartment within that area. This area is made up of compartments and subdivisions joined by interconnecting ventilation system ducting or open hatchways, which are not designed to be secured during general quarters. SCZ's were established using a worst case situation which took into consideration the following conditions:

1. The potential for upward and horizontal smoke movement due to buoyancy, expansion or normal stack effect.
2. The potential for downward movement of relatively cool smoke due to a reverse stack effect.
3. SCZ boundaries must be capable of restricting smoke movement. Fire zone (FZ), watertight (WT), airtight (AT), oil tight (OT) and fume tight (FT) bulkheads are considered applicable for this purpose.
4. Ventilation system closures that are provided at fire zone bulkheads can be secured from both sides of the bulkhead.
5. Ventilation system closures that are provided at other major transverse bulkheads and at the boundaries of vital spaces can only be secured from one side of the bulkhead
6. Ventilation system closures are not always provided at the point of origination and point of termination on vertical ducts.
7. Hatchways located above the main deck are not provided with permanent airtight hatch covers. Portable hatch covers provided for these hatchways cannot be readily installed due to the interference of removable handrailings.

The Smoke Containment and Removal Diagrams (SCRD) consist of a Key Sheet and a Procedure Sheet

KEY SHEET

The Key Sheet, figure 1, illustrates the location and extent of each SCZ. The Key Sheet shows a plan view of all the ship's levels. Each level is segregated into smoke control zones. The SCZ's are designated by number i.e. SCZ 4-1. The first number indicates the deck, platform or level from which the zone originates. The second number indicates the zone location on the level of origination.

The hatched lines indicate areas which are not ventilated. These areas require portable exhaust equipment for smoke removal. The solid colored areas represent compartments which are not subject to smoke penetration such as escape trunks and elevator trunks.

When smoke is detected by the crew, it's location by deck level and frame number, is reported to Damage Control Central or a nearby damage control officer. With this information, the damage control officer pinpoints the compartment on the Key Sheet and immediately knows the areas subject to smoke migration.

PROCEDURE SHEET

Once the damage control officer knows which SCZ is involved, the procedure sheet is referenced. The procedure sheet, figure 2, indicates the actions required to contain smoke within a SCZ and the actions required to remove smoke after the fire has been extinguished.

The procedure sheet indicates:

1. The Smoke Control Zone;
2. Ventilation system fans and closures that should be secured to:

   a. Eliminate the introduction of air to the fire area;
   b. Restrict the migration of smoke and fumes from the affected area;
   c. Reduce the potential for re-ingestion of smoke and fumes;
   d. Address the potential for damage to ventilation ducting which passess through, but does not serve, the fire area.

3. Ventilation system fans that should be energized and ventilation closures that should be opened for smoke removal.

FFG 7 TESTS

The Smoke Containment and Removal Diagrams (SCRD) were developed for the FFG 7 Class ships. These diagrams were tested and evaluated on the USS CLIFTON SPRAGUE (FFG 16). The SCRD effectiveness was measured in their ability to confine smoke within a smoke control zone. Also the de-smoking capability of current shipboard HVAC equipment was investigated. Fans and system closures were secured prior to testing. The tests purpose was not to evaluate the crews ability to interpret and use the diagrams but to see if smoke could be contained in the SCZ.

Four (4) SCZ's were used in evaluating the diagrams. A profile of these zones is shown in figure 3. Condition Zebra Z (secure hatches, doors, and fans) was set before the start of each test.

Chemical smoke, produced by a smoke generator, was used to simulate smoke from a fire. The smoke was formed from a mixture of water, polyethylene glycol-200 and polypropylene glycol. The expansion of fire gases was simulated using a Red Devil Blower, a by pass valve and a Meriam Flowmeter (figure 4). A trace gas, sulfur hexaflorlde (SF_6) was released into the air stream produced by the Red Devil Blower to further simulate fire gases. The migration patterns of SF_6 more closely resemble the migration patterns of smoke gases which can not be simulated with chemical smoke. The SF_6 concentration was monitored by a gas chromatograph.

The tests confirmed that smoke can be effectively contained within a SCZ except for minor leakage through cableway and door seals. Problems were encountered during de-smoking. The two step procedure required to activate the fans - reset circuit breaker at the switchboard and reset local controller - often required in excess of twenty minutes to complete. This was because, in some cases, the local controllers could not be located because of the reduced visibility caused by the smoke. Once the fans serving the affected SCZ were energized, all four of the SCZ's tested could be de-smoked within the required four air exchanges.

CONCLUSION

Recent fires aboard ships have illustrated the hazards of uncontrollable smoke spread. There are many smoke migration routes inherent in current Naval ship designs. The Smoke Containment and Removal Diagrams are pre-engineered instructions for containing smoke within the smallest area possible. Shipboard testing of the diagrams has confirmed that smoke can be affectively contained within a smoke control zone except for minor leakage through cableways and door seals.

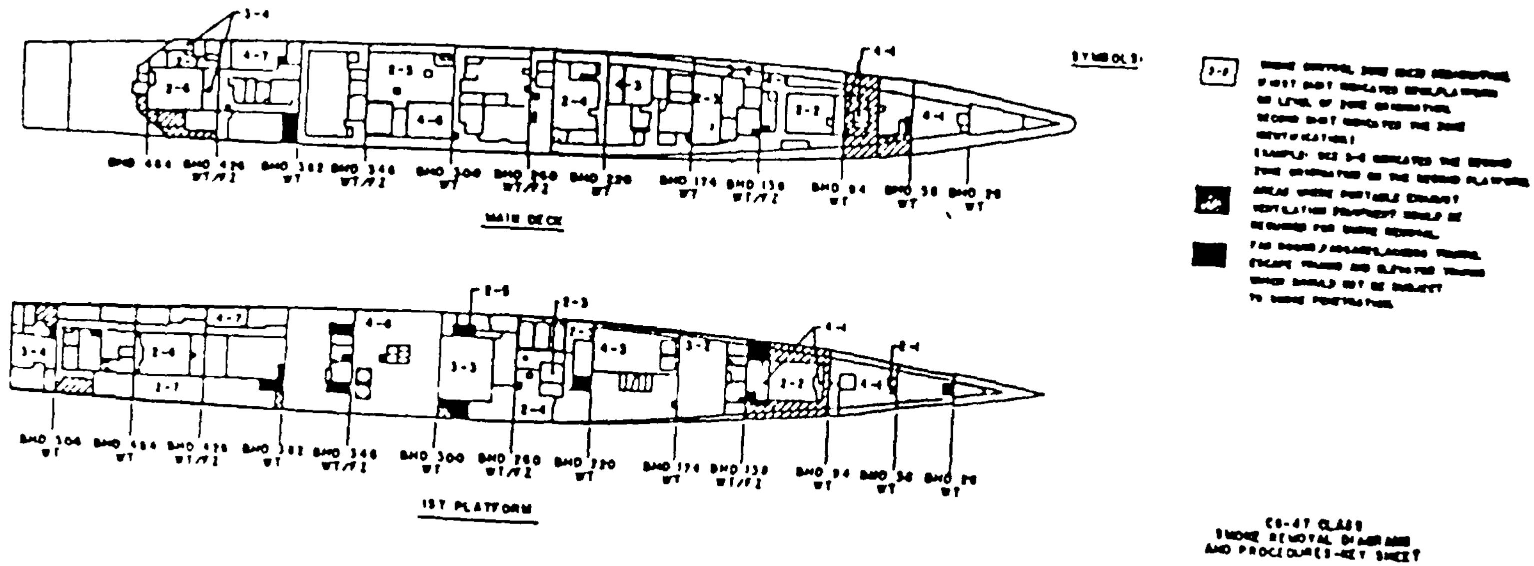


Figure 1. Key Sheet

Chemical smoke, produced by a smoke generator, was used to simulate smoke from a fire The smoke was formed from a mixture of water, polyethylene glycol-200 and polypropylene glycol. The expansion of fire gases was simulated using a Red Devil Blower, a by pass valve and a Meriam Flowmeter (figure 4). A trace gas, sulfur hexaflorlde (SF_6) was released into the air stream produced by the Red Devil Blower to further simulate fire gases. The migration patterns of SF_6 more closely resemble the migration patterns of smoke gases which can not be simulated with chemical smoke. The SF_6 concentration was monitored by a gas chromatograph.

The tests confirmed that smoke can be effectively contained within a SCZ except for minor leakage through cableway and door seals. Problems were encountered during de-smoking. The two step procedure required to activate the fans - reset circuit breaker at the switchboard and reset local controller - often required in excess of twenty minutes to complete. This was because, in some cases, the local controllers could not be located because of the reduced visibility caused by the smoke. Once the fans serving the affected SCZ were energized, all four of the SCZ's tested could be de-smoked within the required four air exchanges.

CONCLUSION

Recent fires aboard ships have illustrated the hazards of uncontrollable smoke spread There are many smoke migration routes inherent in current Naval ship designs. The Smoke Containment and Removal Diagrams are pre-engineered instructions for containing smoke within the smallest area possible. Shipboard testing of the diagrams has confirmed that smoke can be affectively contained within a smoke control zone except for minor leakage through cableways and door seals

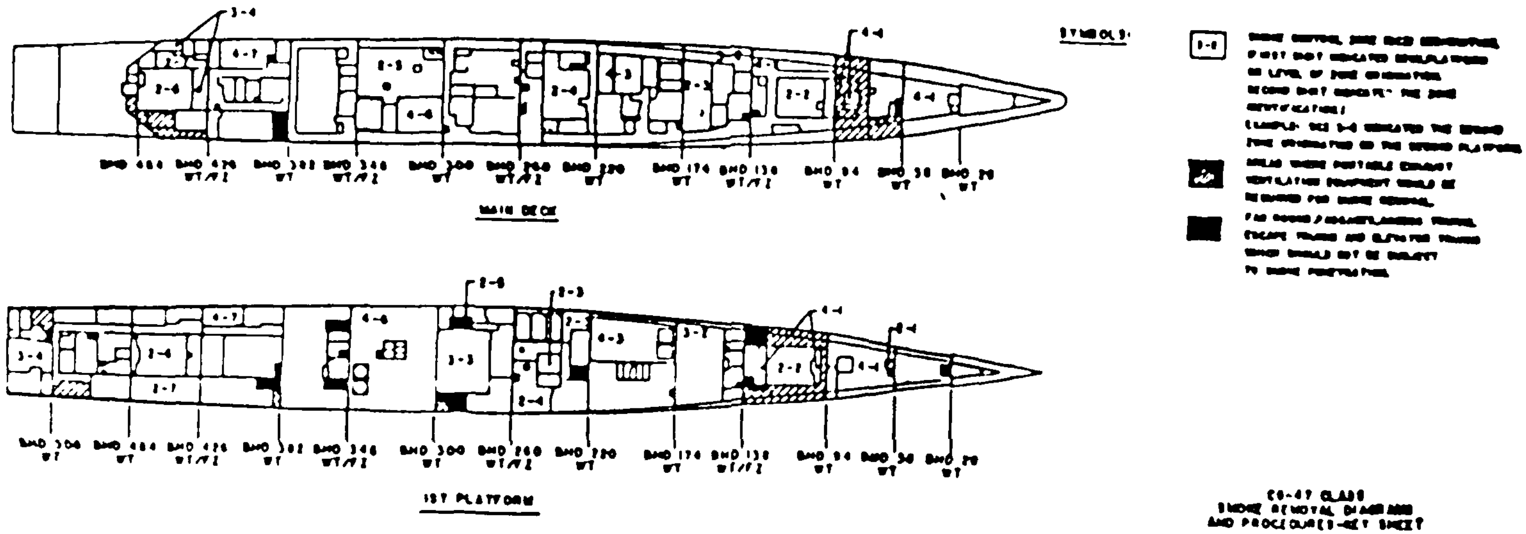


Figure 1. Key Sheet

SCZ	SMOKE CONTAINMENT				SMOKE REMOVAL		
	SECURE				ENERGIZE		OPEN
	FAN SYSTEM				FAN SYSTEM		
	DESIGNATION	DE-ENERGIZED FROM	VENTILATION SYSTEM CLOSURE		DESIGNATION	ENERGIZED FROM	VENTILATION SYSTEM CLOSURE
3-2	S-01-190-1 (W)	TBD	1-139-1 'W'	1-139-6 (Y)	E-01-133-1 'Z'	LC42-4P-1(01-232-1)/1(01-140-1-01	1-139-3 'Z' 1-169-1 'Z'
	S-01-159-1 (Y)	LC11-4P-1(1-80-1)/LC12	1-139-2 (Y)	1-139-7 'W'			1-139-5 'Z'
	S-01-161-1 'X'	LC11-4P-1(1-80-1)/LC12	1-139-3 'Z'	1-139-8 'W'			
	S-01-168-1 'Z'	LC42-4P-1(01-232-1)	1-139-4 'W'	1-139-9 (Y)			
	S-1-87-2 (X)	LC11-4P-1(1-80-1)/LC12	1-139-5 'Z'	1-169-1 'Z'			
	S-2-122-2 'X'	LC11-4P-1(1-80-1)/LC12					
	E-01-141-2 'X'	LC11-4P-1(1-80-1)/LC12					
	E-01-133-1 'Z'	LC42-4P-1(01-232-1)					
	E-01-170-1 'X'	LC11-4P-1(1-80-1)/LC12					
	E-01-172-1 (Y)	LC11-4P-1(1-80-1)/LC12					
	E-3-139-3 (Y)	TBD					
	R-1-150-1 'Z'	1S8-4P-1-8-162-1					
	R-2-171-2 'Z'	TBD					
	R-3-146-8 'Z'	1S8-4P-1-8-162-1					

Figure 2. Procedure Sheet

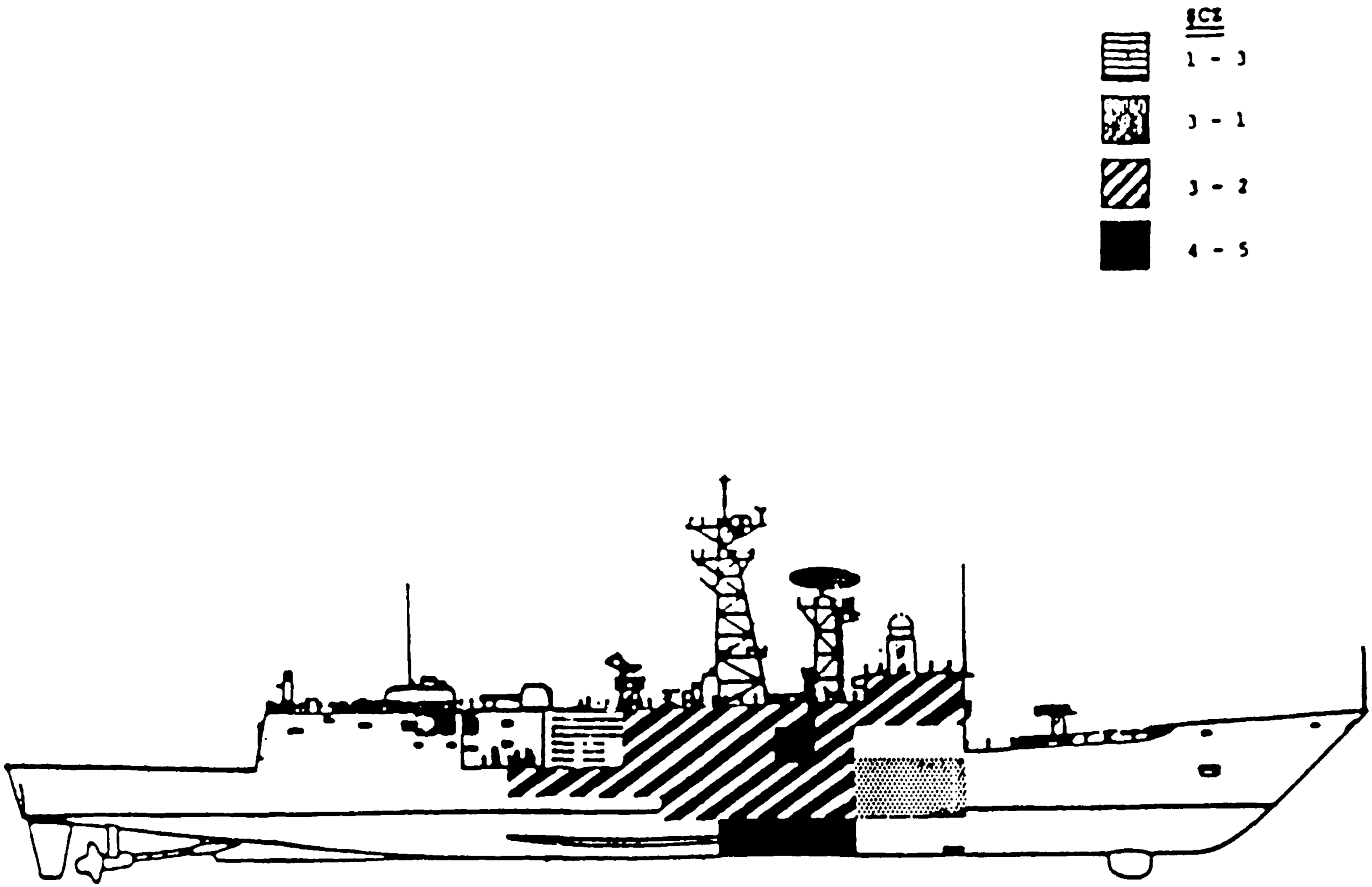


Figure 3. Profile View of Smoke Control Zones

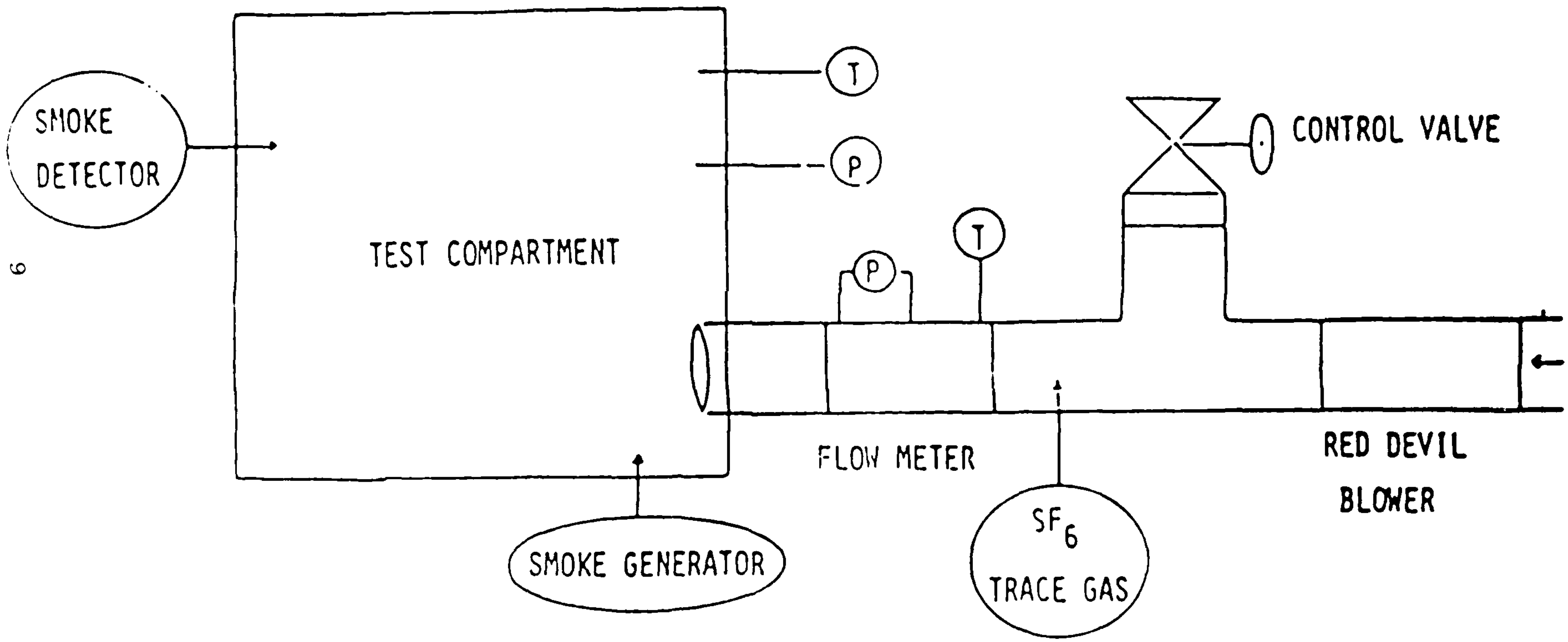


Figure 4. Test Apparatus

MAIN MACHINERY SPACE VENTILATION SYSTEM CONFIGURATION FOR CLASS B FIRES

INTRODUCTION

Fires in main machinery spaces have been one of the most lethal and costly accidents on board US Navy ships to date. The recent deaths of six (6) sailors on board the USS RANGER (CV 61) has prompted the Naval Sea Systems Command to develop a Main Machinery Space Fire Fighting Doctrine. This doctrine identifies the proper procedures for combating the Class B fire problem in main spaces. During the development of the doctrine, questions arose concerning the role of the ventilation system during the initial attack on the fire. Specifically, could tenability thresholds be varied by changing the ventilation settings. Upon further investigation, it was identified that data concerning the varing of the ventilation rates of large scale Class B fires was incomplete, therefore, a test program was initiated.

MACHINERY SPACE VENTILATION

The ventilation rate in main machinery spaces on board most US Navy ships varies according to type of propulsion plant, space size, collective protection system (CPS), ships' manning, and the other major heat producing machinery located within the space. The rate of air change for most machinery spaces is between one (1) and four (4) minutes; the average taken for testing purposes was two (2) minutes. Once the ventilation system supply is computed from the variables above, the exhaust is computed as 115% of supply, this is intended to draw a negative pressure on the space to contain heat and odors from the rest of the ship. There are two other main ventilation settings, low and off. The low ventilaton setting is 66.6% of the high settings and the off ventilation setting is 0% Other ventilation combinations can be achieved such as exhaust off and supply low or high, exhaust low and supply off or high, and exhaust high with supply low or off. The combinations tested were:

Exhaust High (EH) - Supply High (SH)
Exhaust High (EH) - Supply Low (SL)
Exhaust High (EH) - Supply Off (SO)
Exhaust Off (EO) - Supply Off (SO)

The setting of EH was considered to give the maximum heat and smoke removal available while the supply was varied to quantify the adverse affect of suppling oxygen to the fire versus cooling the space with ambient air. The setting of EO-SO was used as a base line of fire severity

TEST SITE

A unique facility was needed to test different ventilation settings during large scale fires in the machinery space configuration The space chosen was the machinery space fire fighting trainer located at the Damage Control School at Treasure Island, CA This trainer had the space configuration, burnability, and was easily modified to simulate a main space fire.

The ventilation system was simulated by using two, 12,000 cubic feet per minute (cfm) centrifugal fans, 36 inch and various smaller size ducting, and dampers. One fan drew from the top of the space as the exhaust, the other was dampered to regulate the flow and acted as the supply A network of smaller ductwork was constructed inside the space to simulate the actual supply system for a machinery space.

TESTING

The actual testing consisted of a spray fire and five (5) different size pools. The spray was created by a small crack in a pressurized diesel fuel line. Approximately 6.5 gallons per minute (gpm) flowed from the line and produced 15.0 megawatts (Mw) of energy. The pool fires were 10, 25, 50, 100, and 900 square feet in size and produced .96, 2.4, 4.7, 9.5, and 15.0 Mw of energy, respectfully. The energy release rates can be controlled by the amount of oxygen available and is related to the ventilation rate of the space.

The space was instrumented for temperature, fuel mass loss, gas concentration levels, smoke density, radiant heat, differential pressure, ventilation flow rate, and video recording. The main factors concerning the tenability of the space were visibility, carbon monoxide (CO) production, and temperature.

The threshold limits for tenability were:

Visibility	10 feet (ft)
CO Production	3000 parts per million (ppm)
Temperature	300° Fahrenheit (F)

RESULTS

The data concluded that the fires that could be fought for a short time, but would eventually pass the tenability thresholds were the 25 and 50 square feet fires. The 10 square feet fire could burn for a relatively long period of time without reaching the limits and the 100, 900 square feet and spray fire lost tenability in a relatively short period of time after ignition (approximately 20 seconds). Tables 1 and 2 give the relative time until tenability limits were reached on the lower (L1) and upper (L2) levels

CONCLUSIONS

The following conclusions were made from the results.

1. The one hundred (100) square feet fires reach untenable conditions due to smoke obscuration in approximately twenty (20) seconds, irrespective of ventilation configuration. Critical CO and temperature conditions are reached between sixty (60) and eighty (80) seconds.
2. Spray fires reach temperature limits between eighteen (18) and twenty-eight (28) seconds for all ventilation configurations (eighteen (18) seconds supply off/exhaust off).
3. Spray fires generate the highest CO levels for all tests.
4. Conditions quickly deteriorate on the upper level, for most tests a loss of visibility occurred within two (2) minutes.
5. Worst ventilation configuration overall was supply off/exhaust off.
6. Ventilation configuration recommended for doctrine is supply low/exhaust high or supply high/exhaust high.

Table 1. Pool Fire (50 Square Feet)

Test No	Ventilation Setting	Temperature (Sec) L1	Temperature (Sec) L2	CO (Sec) L1	CO (Sec) L2	Visibility (Sec) L1	Visibility (Sec) L2
10	SO/EO	-	68	240	180	38	15
11	SO/EH	-	75	370	270	45	15
22	SL/EH	-	80	-	210	45	10
27	SH/EH	-	80	-	-	50	10

Table 2. Pool Fire (25 Square Feet)

Test No	Ventilation Setting	Temperature (Sec) L1	Temperature (Sec) L2	CO (Sec) L1	CO (Sec) L2	Visibility (Sec) L1	Visibility (Sec) L2
6	SO/EO	-	180	-	-	20	20
9	SO/EH	-	-	-	-	75	-
20	SL/EH	-	-	-	-	35	35
19	SH/EH	-	-	-	-	65	40

SMOKE EJECTION SYSTEM

INTRODUCTION

Beginning in 1981, David Taylor Naval Ship Research & Development Center (DTNSRDC) conducted a series of live fire tests investigating the use of ventilation fans, ducting, and dampers to control smoke during fires. These tests were performed at the US Coast Guard Fire Test and Safety Facility in Mobile, AL. The US Coast Guard vessel ALBERT E. WATTS was the test vessel. These tests demonstrated that smoke from live fires could be controlled on one deck or in a multi-deck situation. The test series performed in 1985 was conducted in a 3-deck, multi-compartment zone. Two abutting zones and an imbedded machinery space were simulated in this test. We found that smoke could be controlled during a fire using the ship's ventilation system. Figure 5 compares the present doctrine, securing the ventilation during fire, with the proposed concept of using the ventilation in a controlled engineered system to remove both heat and smoke. When ventilation is secured in accordance with present doctrine, we see the 02 Deck rapidly filling with smoke but when we use the ventilation system in an engineered manner, smoke does not penetrate the 02 Deck and the temperatures on the 01 Deck within close proximity to the fire remains tolerable. If the 02 Deck does become filled with smoke as with securing the ventilation in figure 5, we found that the smoke could be removed once the ventilation was reset. Figure 6 shows that the totally obscured passage has cleared sufficiently within seven (7) minutes after ventilation restart for easy movement of personnel. Within seventeen (17) minutes after starting the ventilation and five (5) minutes after the fire was extinguished, the visibility has returned to near normal.

Combining this experience with concepts used in systems developed for Veteran Administration hospitals and new high rise hotels, a system for control of smoke is feasible. Requirements for smoke control are:

1. Smoke movement between areas can be controlled if the average air velocity is of significant magnitude;
2. Air pressure across barriers can act to control smoke movement;
3. Smoke movement between areas can be controlled if barriers or compartmentalization are used;
4. Stack effect, buoyancy, and wind effects are less likely to overcome smoke control than passive smoke management;
5. Smoke control can be designed to prevent smoke flow through an open doorway in an barrier by use of air flow, and
6. An exhaust path for smoke movement to the outside is required.

Ship design inherently provides the ability to satisfy all of the requirements. That is, a ship has compartments, a ship has fans which can develop pressures and air flows, and a ship has an exhaust path to weather. The only item missing is engineering to integrate these parts into a functioning system. Based on these tests, the guidelines for the Smoke Control Diagrams and Procedures, the new Main Machinery Space Fire Fighting Doctrine, the Smoke Ejection System and several other projects evolved.

SYSTEM DEFINITION

What is the Smoke Ejection System (SES)? The Smoke Ejection System is an engineered system fully integrating the ship's heating, ventilating, and air conditioning system. It utilizes the mechanical fans and dampers to produce air flows, pressure differences, and to eject smoke, heat and toxic gases from the ship to the weather.

SYSTEM FUNCTION

How does the Smoke Ejection System work? On a ship having the Smoke Ejection System (SES), the smoke can be controlled in areas serviced by a fresh air supply duct and an exhaust to the weather. This area may be a single space or multiple spaces. We define this area as a smoke control area. A simple single space smoke control area is shown in figure 7. The fire scenario for a ship having SES is:

1. Fire detection;
2. Set the smoke ejection system (close the air supply damper);
3. Try to extinguish the fire (on site personnel, if present; failing to do this, retreat from the area);
4. Secure all hatches and doors;
5. Form fire parties, re-enter the fire/smoke area;
6. Extinguish the fire; and
7. De-smoke

The fire fighters will encounter only minimal smoke, visibility will not be impaired, temperatures will be lower than those presently encountered and the fire fighters will proceed rapidly to the seat of the fire. Presently, we have targeted the second flight of the DDG 51 Class for the Smoke Ejection System (SES). Applying this concept to the DDG 51, Frame 126-174, First Platform, figure 8, we find four (4) smoke control areas: Port Passage, Starboard Passage, Communications and Radio Transmitter Room and CSER 2. The HVAC for these areas under normal operation, figure 9, item (a) and during fire fighting operations, figure 9, item (b) differ only in that the air supply to the fire compartment, Communications and Radio Transmitter Room is secured. The + signs, figure 9, item (b) indicate that the adjacent spaces will eventually develop a slightly higher pressure than the fire area.

SYSTEM IMPACT

Why use a Smoke Ejection System? As shown earlier using the smoke control diagrams and procedures we are able to confine smoke to a perdetermined zone. The zone is in most cases very large. The number of actions required to set this zone are also numerous. An example of using the smoke control diagrams and procedures for the DDG 51 is shown in figure 10, item (a) and the list of actions required by the sailor is shown in figure 11, item (a). On the other hand, if we integrate the control and removal of smoke into the design of the HVAC system of the ship, the SES, minimal changes are required, and the impact on space, weight and cost is small. In this system, the smoke is confined to the area of origin and only one action is required - secure the air supply to the area. This concept is pictured in figure 10, item (b) and the

actions required to establish this condition are listed in figure 11, item (b). When we compare the DDG 51 with collective protection system (CPS) to the DDG 51 with SES, figure 12, we find that the survivability of the DDG 51 is increased.

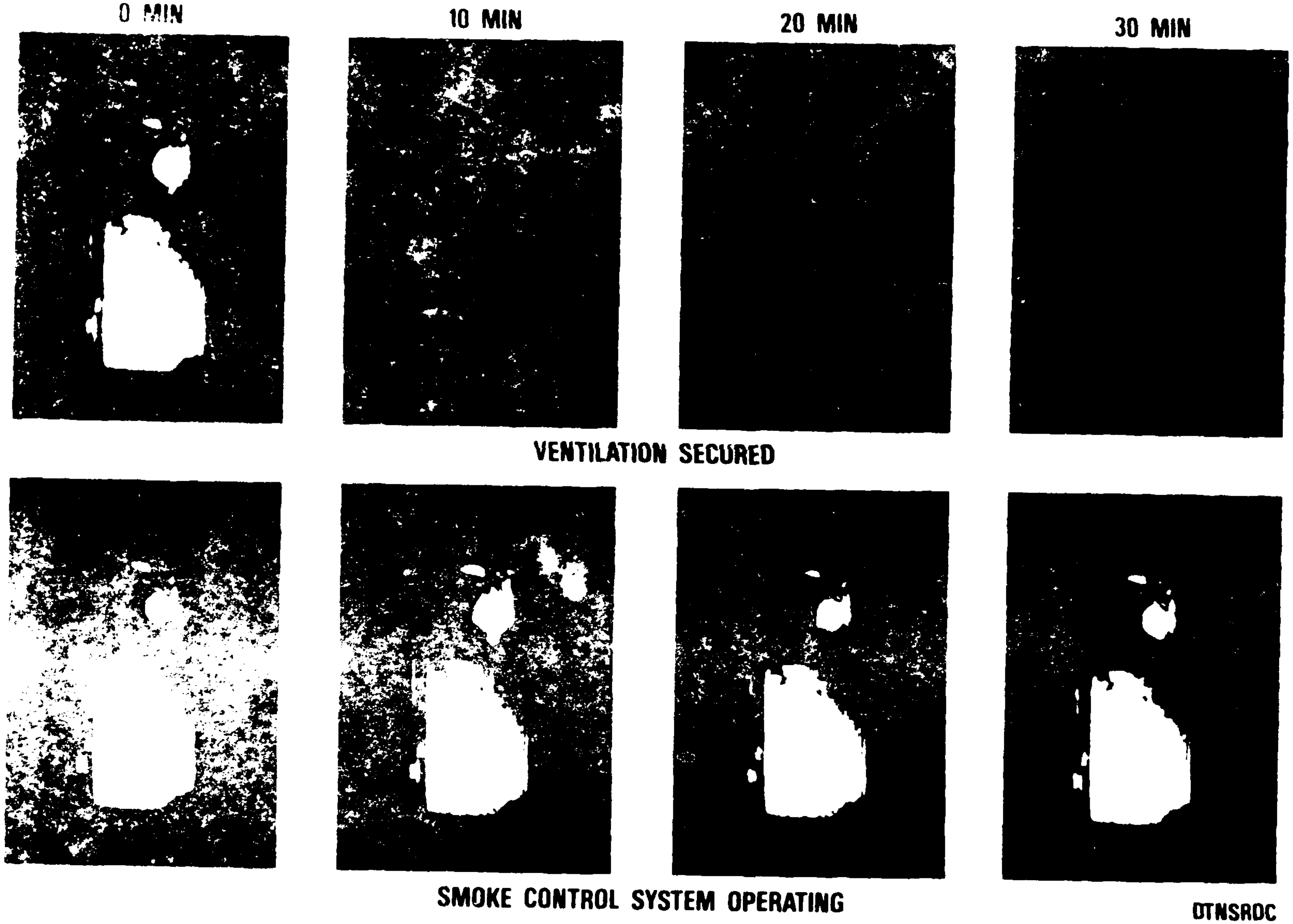
PLANS

A Smoke Ejection System for one fire zone has been designed for installation on the Advanced Fire Research Ship, Ex-USS SHADWELL. The fire zone utilizes from the Bow to Frame 36, (144 feet approximate) and includes the superstructure decks. The system design provides large smoke ejection capability, 1200 cubic feet per minute or greater, for critical area such as the Combat Information Center, Communications and Radio Transmitter Room, etc. and provides the option to increase the exhaust capability to all spaces to a minimum of 500 cubic feet per minute. Three collective protection systems (CPS) will be integrated into the smoke ejection system. Two CPS systems will provide the normal fresh air ventilation for the spaces and the third system is the ventilation for a galley. Although the installation on the Advanced Fire Research Ship is generic, a comparison matrix of spaces with typical spaces on the DDG 51 pressure zone/fire zone 2 has been made in table 3. This comparison shows that the size of most DDG 51 spaces can be approximated on the test ship; deck location may vary in some cases.

Installation of the system on the Advanced Fire Research Ship will be completed in June 1987. Installation of test equipment and instruments should be completed by January 1987 and the first test should begin shortly thereafter. We will fully test the system using both chemical smokes (non-destructive) and live fires. Operation of the system is manual and we will integrate the sailor/fire fighter into the tests.

SMOKE PENETRATION, 02 DECK (FIRE ON 01 DECK)

TIME AFTER IGNITION



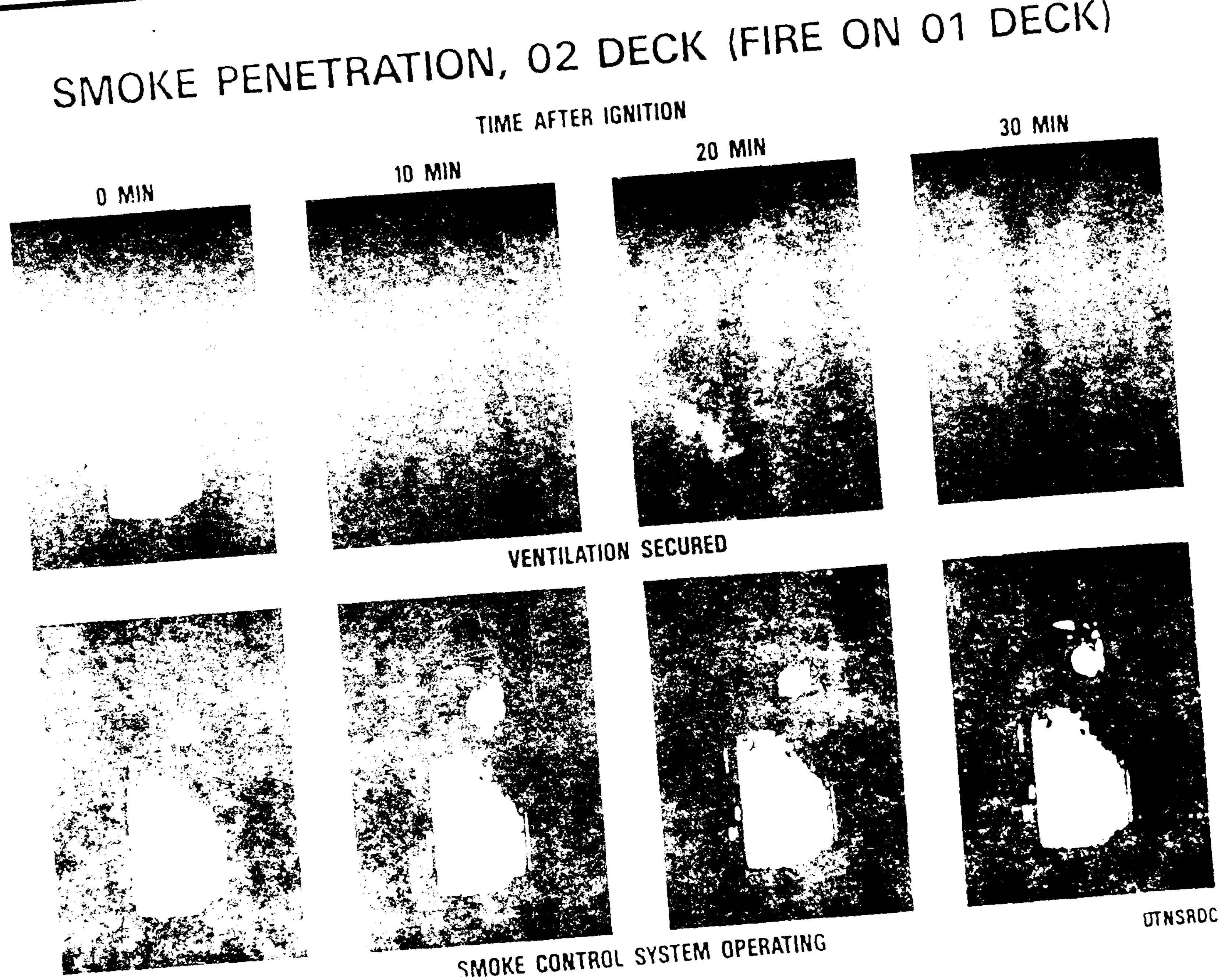
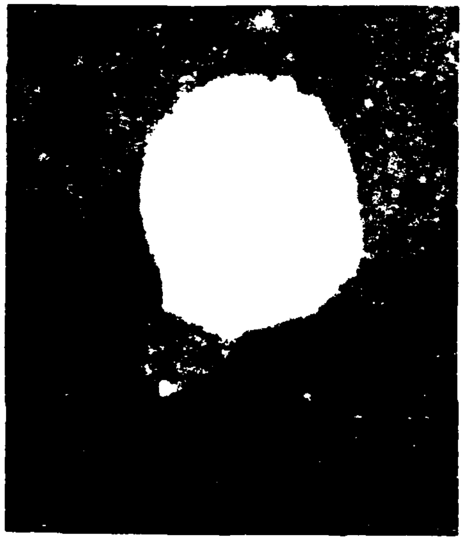


Figure 5. Smoke Penetration, 02 Deck (Fire on 01 Deck)

SMOKE CLEAN-UP, 02 DECK (FIRE ON 01 DECK)

TIME AFTER IGNITION

40 MIN

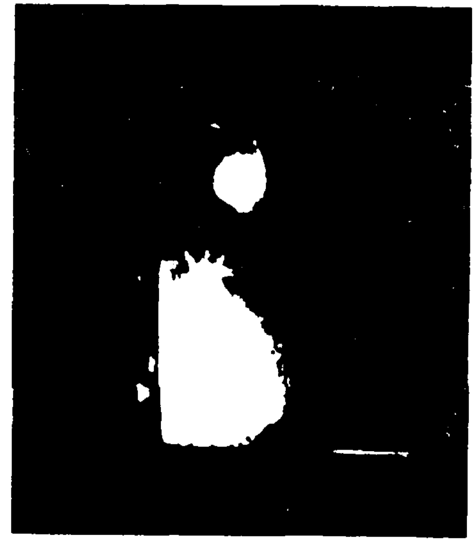


7 MIN

50 MIN

17 MIN

60 MIN



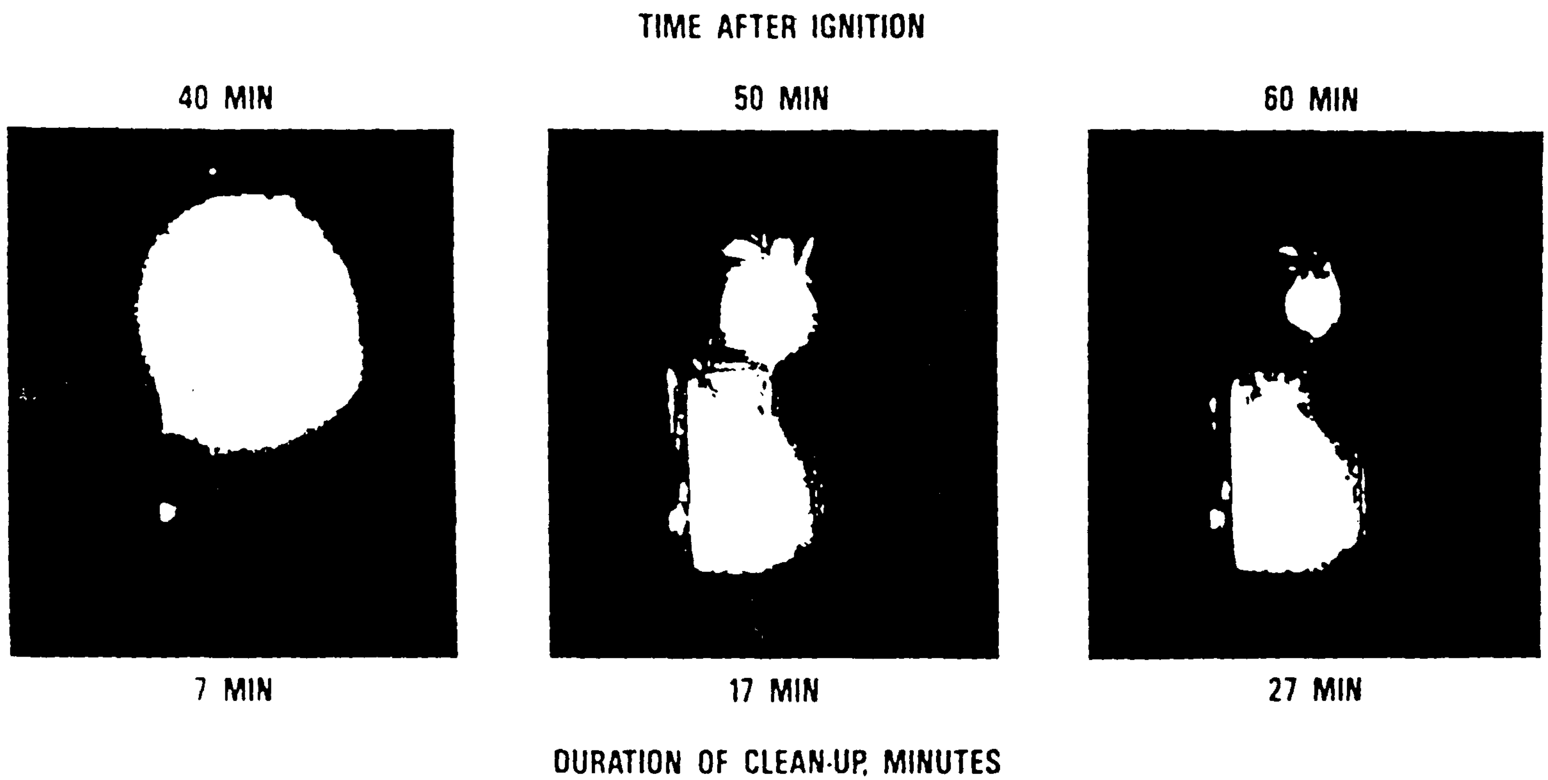
27 MIN

DURATION OF CLEAN-UP, MINUTES

33 MINUTES AFTER IGNITION, SMOKE CONTROL SYSTEM STARTED
45 MINUTES AFTER IGNITION, FIRE EXTINGUISHED

DTNSRDC

SMOKE CLEAN-UP, 02 DECK (FIRE ON 01 DECK)



33 MINUTES AFTER IGNITION, SMOKE CONTROL SYSTEM STARTED
45 MINUTES AFTER IGNITION, FIRE EXTINGUISHED

DTNSRDC

Figure 6. Smoke Clean-up, 02 Deck (Fire on 01 Deck)

SMOKE CONTROL ZONE

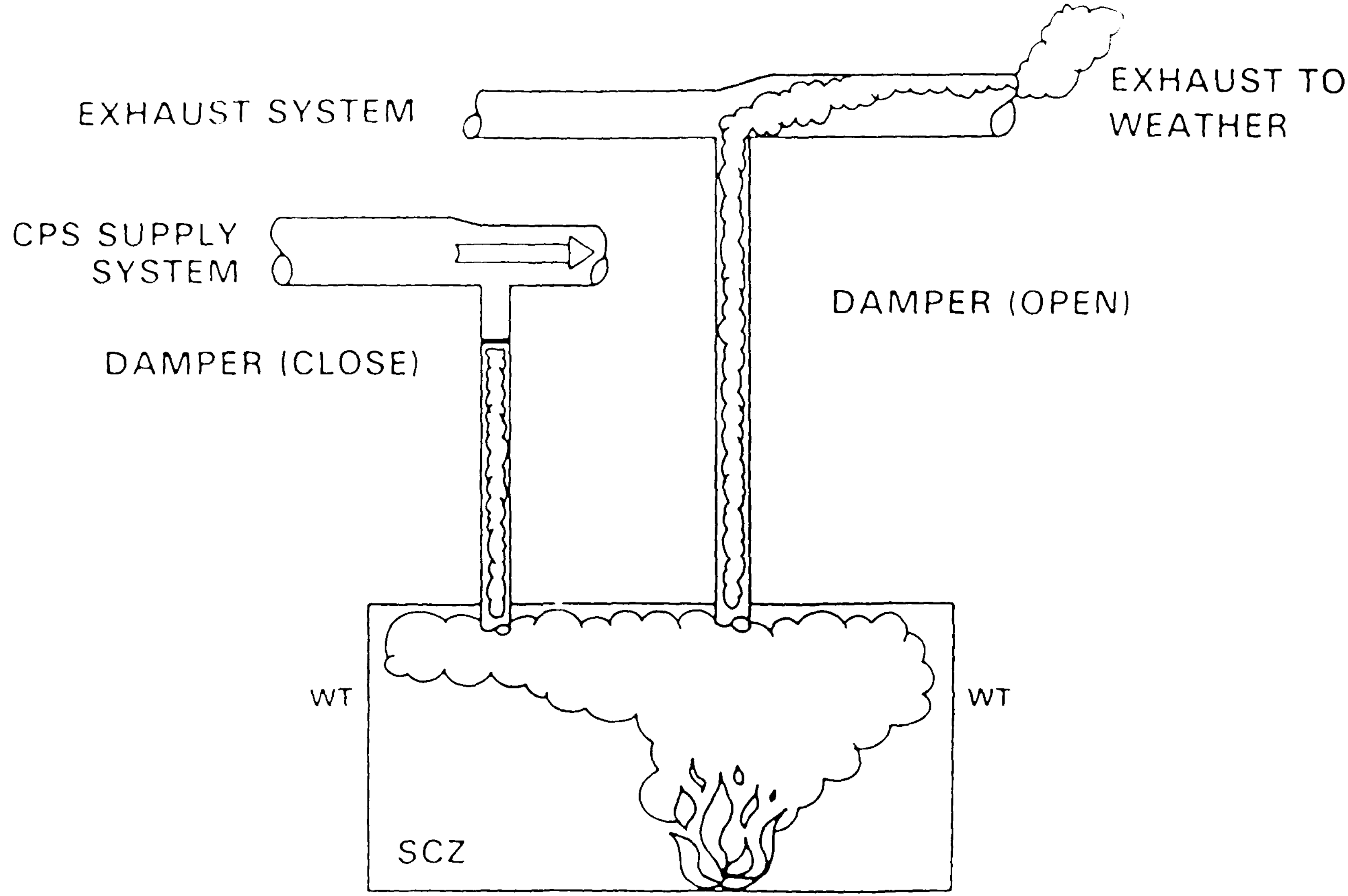


Figure 7. Smoke Control Area

SMOKE CONTROL ZONES
FR 126 - 174

FIRST PLATFORM

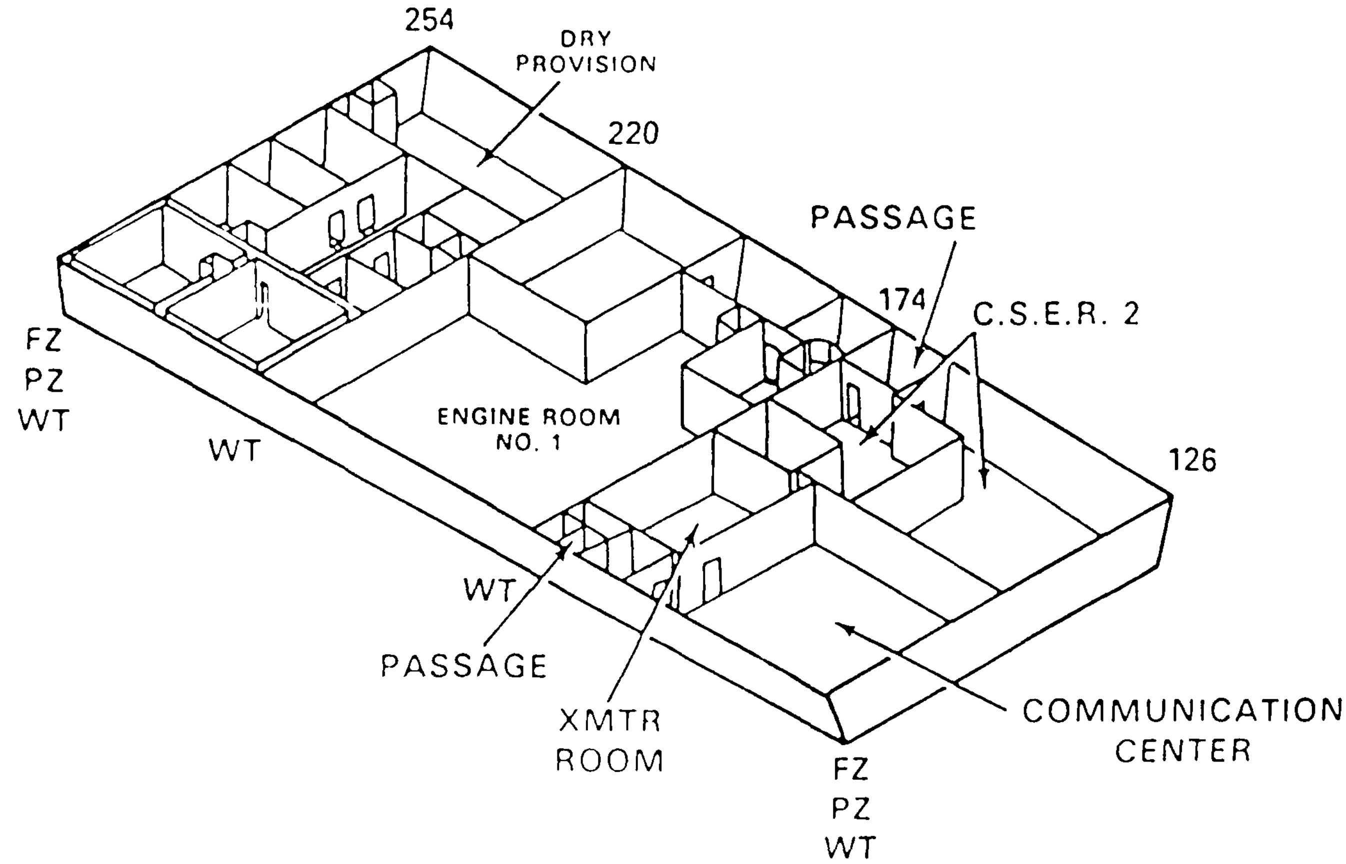


Figure 8. Smoke Control Area, DDG 51, First Platform, Frame 126 - 174

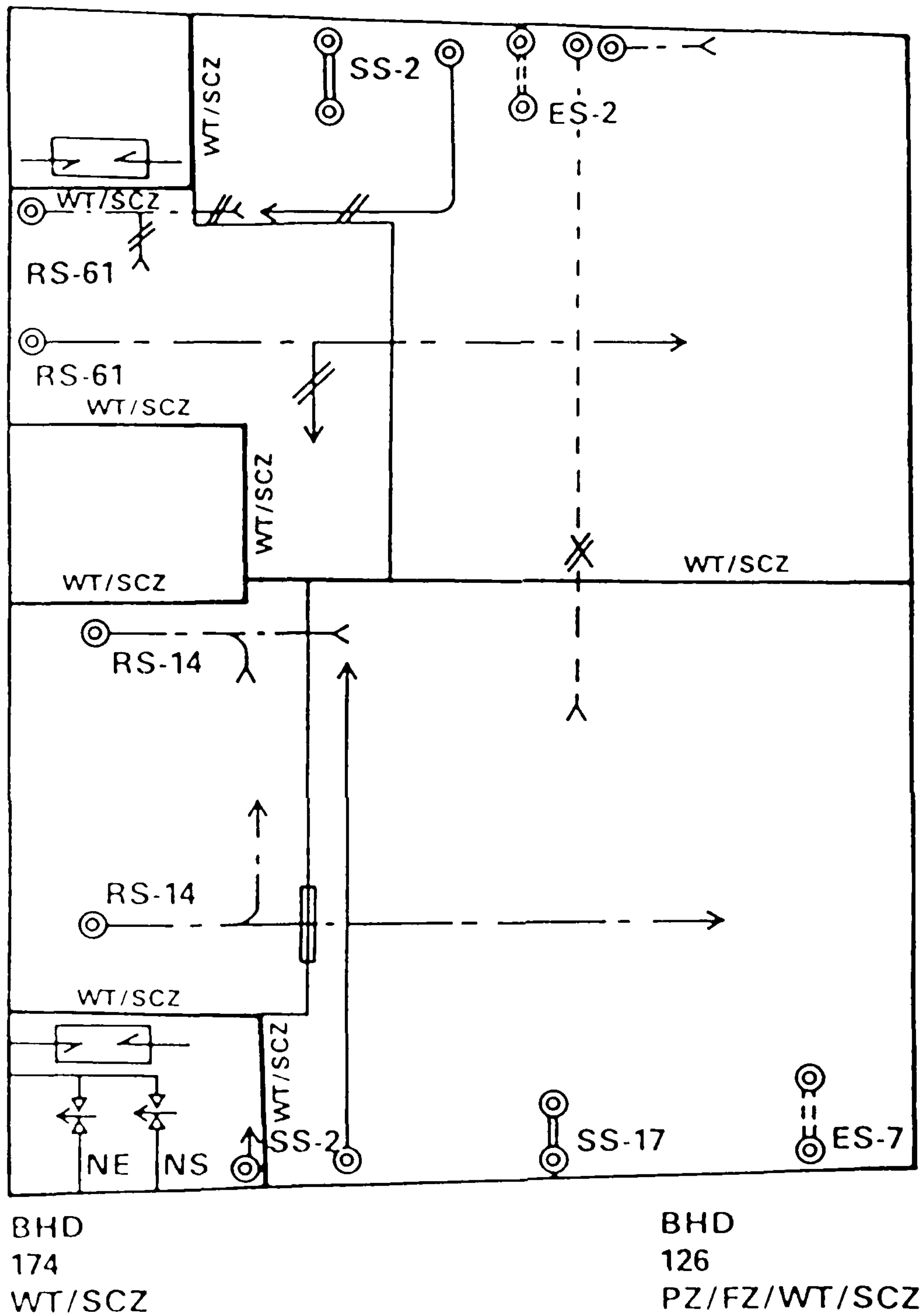


Figure 9. HVAC for DDG 51, First Platform, Frame 126 - 174 Item (a) Normal Ventilation

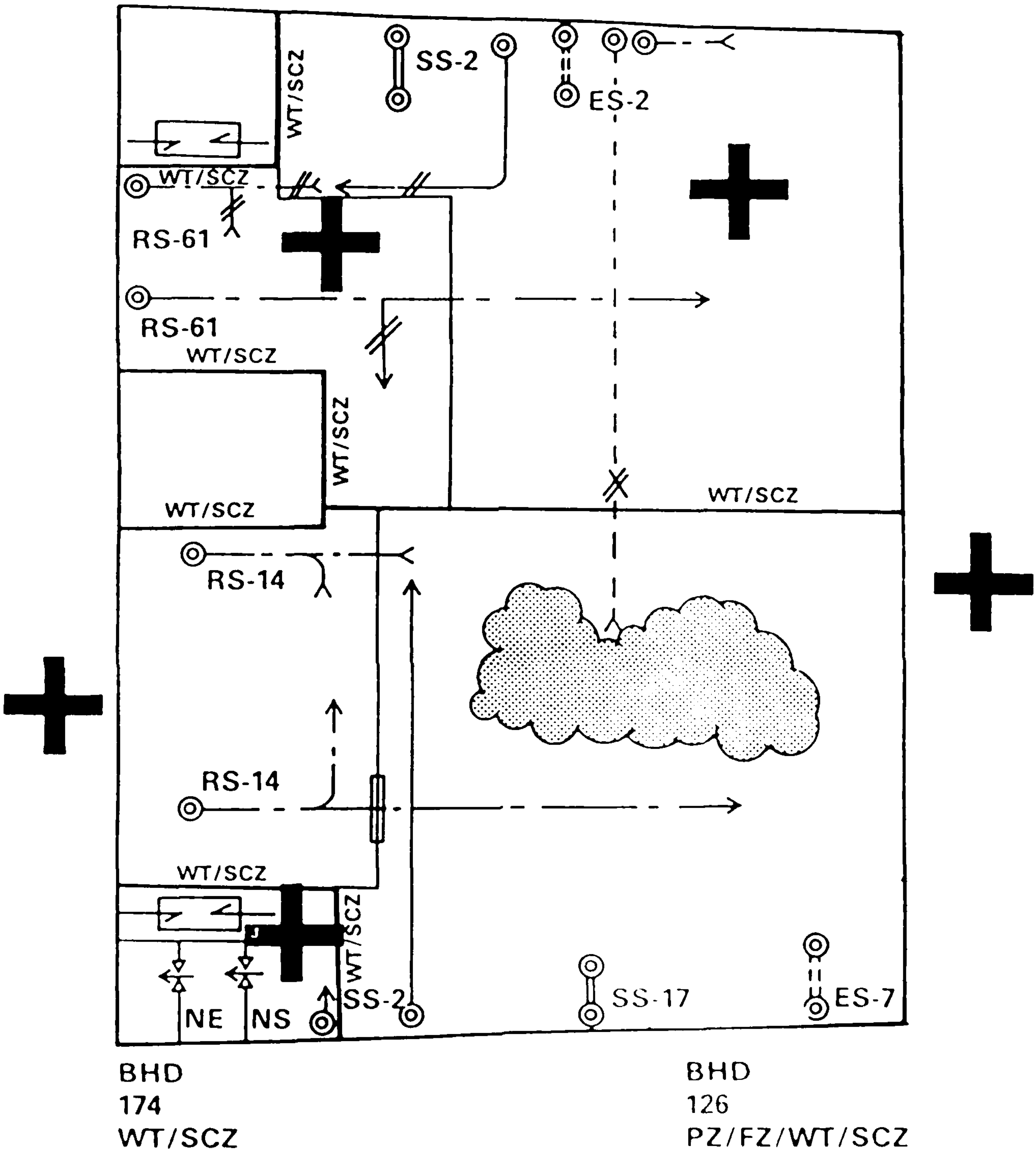
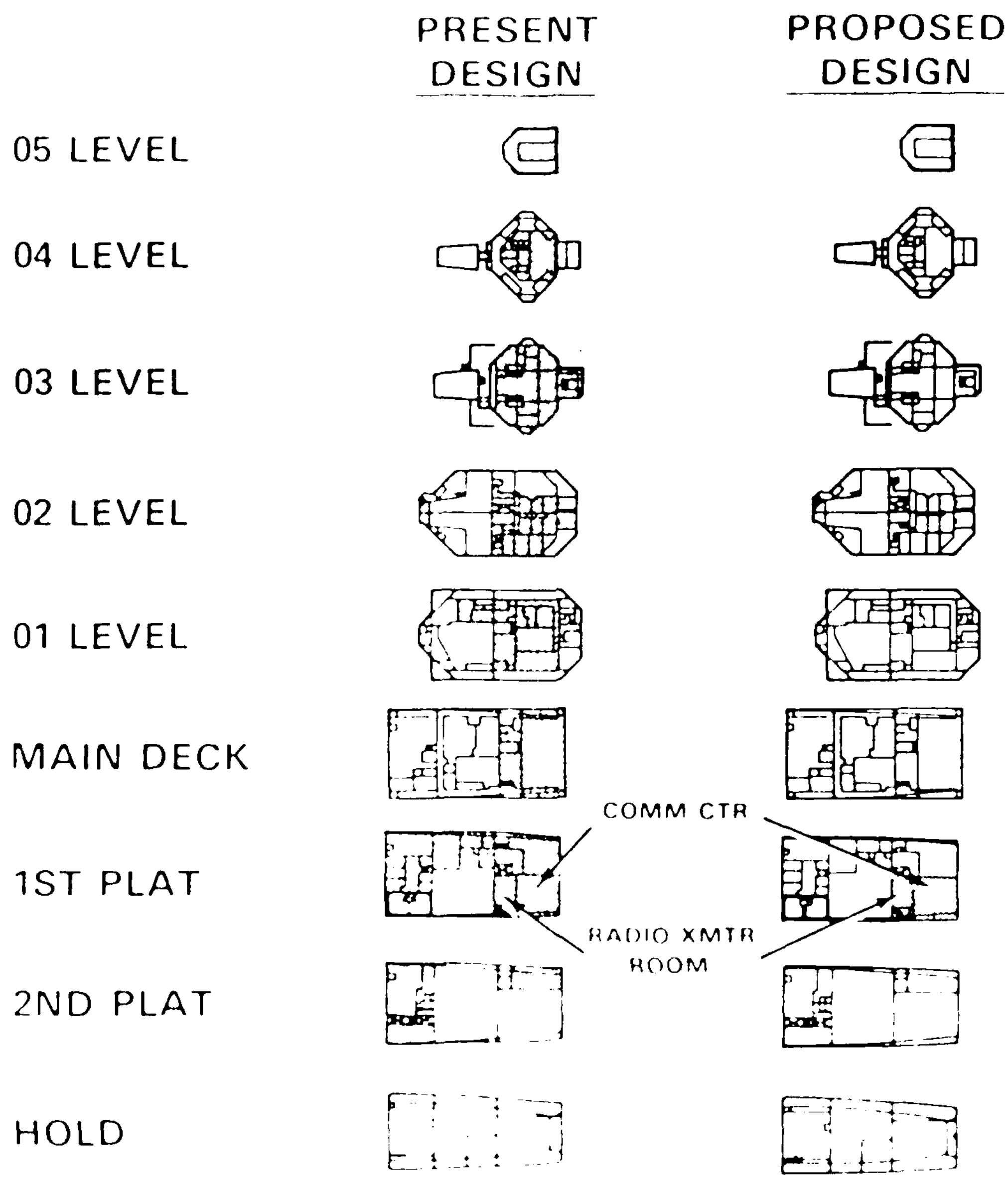


Figure 9. HVAC for DDG 51, First Platform, Frame 126 - 174 Item (b) Smoke Ejection

PROJECTED AREAS OF SMOKE INVOLVEMENT

FIRE SCENARIO: COMMUNICATIONS CENTER/RADIO XMTR ROOM FIRE



DDG-51 FIRE ZONE NO. 2

Figure 10. Projected Areas of Smoke Involvement

DDG-51 SMOKE REMOVAL/ CONTROL PROCEDURES

FIRE SCENARIO: COMMUNICATIONS CENTER/RADIO XMTR ROOM FIRE

PRESENT DESIGN

SMOKE CONTAINMENT			SMOKE REMOVAL		
SECURE			ENERGIZE		OPEN
FAN SYSTEM		VENTILATION SYSTEM CLOSURE	FAN SYSTEM		VENTILATION SYSTEM CLOSURE
DESIGNATION	DE-ENERGIZED FROM		DESIGNATION	ENERGIZED FROM	
SS 2 W	TBD	1 158 2 Z 2 156 1 W	SS 2 W	TBD	1 158 4 W 2 150 2 W
SS 5 W	1S 4P (02 185 2)/LC21	1 158 4 W 2 169 1 W	ES 2 W	TBD	1 175 1 W 2 156 1 W
SS 7 W	TBD	1 167 2 Z 2 169 3 W	RS 4 W	1S 4P (1 175 1)	2 147 2 W 3 147 2 W
SS 17 W	TBD	1 175 1 W 2 173 2 W	RS 5 W	TBD	2 144 2 W 3 156 2 W
SS 18 W	1S 4P (02 185 2)/LC21	1 175 2 W 2 173 4 W	RS 8 W	1S 4P (01 170 2)	
ES 2 W	TBD	1 175 4 W 3 147 2 W	RS 10 W	1S 4P (1 175 1)	
ES 5 W	1S 4P (02 185 2)/LC21	2 141 2 W 3 156 2 W	RS 11 W	1S 4P (1 175 1)	
ES 7 W	TBD	2 144 2 W 3 164 2 W	RS 12 W	1S 4P (1 175 1)	
ES 9 W	3S 4P (01 256 2)/LC31)	2 150 2 W 3 164 4 W	RS 13 W	1S 4P (01 170 4)	
ES 10 W	3S 4P (01 300 1)/LC31		RS 14 W	1S 4P (01 170 4)	
RS 1 W	1S 4P (1 175 1)		RS 15 Z	TBD	
RS 2 W	1S 4P (1 175 1)		RS 28 Z	TBD	
RS 3 Z	1S 4P (1 175 1)		RS 45 W	TBD	
RS 4 W	1S 4P (1 175 1)		RS 46 W	3S 4P (1 280 4)	
RS 5 W	TBD		RS 61 W	3S 4P (1 280 6)	
RS 6 Z	1S 4P (01 170 2)				
RS 8 W	1S 4P (01 170 2)				
RS 10 Z	1S 4P (1 175 1)				
RS 11 W	1S 4P (1 175 1)				
RS 12 W	1S 4P (1 175 1)				
RS 13 W	1S 4P (01 170 4)				
RS 14 W	1S 4P (01 170 4)				
RS 15 Z	TBD				
RS 28 Z	TBD				
RS 45 Z	TBD				
RS 46 W	3S 4P (1 280 4)				
RS 47 W	3S 4P (1 280 4)				
RS 60 W	LC2 4P (01 170 6)				
RS 61 W	3S 4P (1 280 6)				
RS 62 Z	3S 4P (1 290 1)				

PROPOSED DESIGN

SMOKE CONTROL				
SECURE				OPEN
FAN SYSTEM		VENTILATION SYSTEM CLOSURE	SMOKE CONTROL DAMPER	SES DAMPER
DESIGNATION	DE ENERGIZED FROM			
ES [illegible] W	TBD		1 141 [illegible] 1 [illegible]	
ES 9 W	3S 4P (01 256 2)/LC31		1 142 [illegible] 1 172 [illegible]	
RS 14 W	1S 4P (01 170 4)			

Figure 11. DDG 51 Smoke Removal/Control Procedures

COMPARISON DDG-51 CLASS VENTILATION SYSTEM DURING FIRE FIGHTING

DDG-51 CLASS (CPS)	DDG-51 CLASS (CPS) WITH SES
• SUPPLY FAN/SYSTEM SECURED TO ENTIRE FIRE ZONE	• SUPPLY AIR SECURED IN SMOKE CONTROL ZONE
• EXHAUST FAN/SYSTEM SECURED TO ENTIRE FIRE ZONE	• EXHAUST SECURED TO ADJACENT NON-INVOLVED SMOKE CONTROL ZONES
• CPS CAN NOT BE MAINTAINED	• CPS FULLY OPERATIONAL
• SMOKE, TOXIC AND CORROSIVE GASES SPREAD TO ENTIRE ZONE	• SMOKE, TOXIC AND CORROSIVE GASES CONFINED TO SMOKE CONTROL ZONE
• DE-SMOKING AFTER FIRE EXTINGUISHED	• SMOKE, TOXIC AND CORROSIVE GASES EJECTED IN A CONTROLLED MANNER TO THE WEATHER
• CONFLICTS WITH FIRE FIGHTING	• COMPLEMENTS FIRE FIGHTING

Figure 12. Comparison DDG 51 Class Ventilation System During Fire Fighting

Table 3. DDG 51 Class - Ex-USS SHADWELL LSD 15 Space Matrix

DDG 51 CLASS

SMOKE CONTROL AREA	COMPARTMENTS	DK AREA (sq ft)	VOL (cu ft)	VENT AIR (cfm)	R/C (min)
04 LVL	PILOT HOUSE AREA	1008	8568	570	15.0
01 LVL	SHOWER, EXEC OFF SR, OPS OFF, ADMIN OFF, TECH LIBRARY, PASS	936	7956	75	106.1
02 LVL	WR MESS, WR GALLEY	684	5472	600	9.1
02 LVL	STATEROOMS, SHOWER, PASSAGE, CO SR, DH SR, CO SHOWER	1696	13568	480	28.3
02 LVL 03 LVL	CIWS, CIWS WORKSHOP	523	3784	400	9.5
01 LVL	DECON STA	216	1836	420	4.4
01 LVL	TECH LIBRARY & REP 8	476	4046	120	33.7
MN DK	MESSROOM, SCULLERY	1414	13074	2600	5.0
01 LVL	FILTER CLNG RM, ELEX WORKSHOP	442	3757	300	12.5
05 LVL	DIRECTOR EQPT RM	196	1372	100	13.7
1ST PL	CSER NO. 2	1164	10476	75	139.7
1ST PL	COMM CTR & RADIO XMTR ROOM	1323	12238	110	111.3

EX-USS SHADWELL LSD 15

SMOKE CONTROL AREA	COMPARTMENTS	DK AREA (sq ft)	VOL (cu ft)	VENT AIR (cfm)	R/C (min) NOTE 2
BR DK	PILOT HOUSE AREA	1080	8002	520	15.4
SS DK NOTE 1	SHOWER, EXEC OFF SR, OPS OFF, ADMIN OFF, TECH LIBRARY, PASS	692	5161	75	68.8
SS DK NOTE 1	WR MESS, WR GALLEY	593	4423	485	9.1
SS DK NOTE 1	STATEROOMS, SHOWER, PASSAGE, CO SR, DH SR, CO SHOWER	1416	10560	400	26.4
SS DK MN DK NOTE 1	CIWS, CIWS WORKSHOP	380	3019	180	16.8
MN DK	DECON STA	308	2605	420	6.2
MN DK	TECH LIBRARY & REP 8	230	2070	75	27.6
MN DK	MESSROOM, SCULLERY	600	5400	715	7.6
MN DK	FILTER CLNG RM, ELEX WORKSHOP	422	3798	260	14.6
MN DK	DIRECTOR EQPT RM	280	2368	75	31.6
2ND DK	CSER NO. 2	600	7250	75	96.7
2ND DK	COMM CTR & RADIO XMTR ROOM	872	9992	75	133.2

Table 3. (Continued)

DDG 51 CLASS

SMOKE CONTROL AREA	COMPARTMENTS	DK AREA (sq ft)	VOL (cu ft)	VENT AIR (cfm)	R/C (min)
1ST PL	CPO LIVING, TOILET, & SHR (TYPICAL)	476	4284	205	20.9
------	NOT ON DDG 51	----	----	----	----
MN DK	CIC, CIC OFFICE	2192	20824	375	55.5
------	NOT ON DDG 51	----	----	----	----
2ND PL	BOSN STRS (TYPICAL)	340	3060	----	----
MN DK	PASS (P) - ON DC DK	154	1425	----	----
MN DK	PASS (S) - ON DC DK	154	1425	----	----
1ST PL	GEN WORKSHOP, LAB, PASSAGE	796	7164	375	19.1
1ST PL	LAUNDRY	667	6003	2400	2.5
2ND PL	CHEM WARFARE DEF STRM	323	2907	----	----
2ND PL	CREW LIVING, TOILET, & SHR (TYPICAL)	720	6120	285	21.5

EX-USS SHADWELL LSD 15

SMOKE CONTROL AREA	COMPARTMENTS	DK AREA (sq ft)	VOL (cu ft)	VENT AIR (cfm)	R/C (min) NOTE 2
2ND DK	CPO LIVING, TOILET, & SHR (TYPICAL)	300	3297	185	17.8
2ND DK	CARPENTER SHOP (TYPICAL)	280	2823	115	24.5
2ND DK NOTE 1	CIC, CIC OFFICE	1620	16200	260	62.3
2ND DK	PALLET HDLG & STWG (TYPICAL)	336	3696	115	32.1
2ND DK	BOSN STRS	280	2823	75	37.6
2ND DK NOTE 1	PASS (P) - ON DC DK	336	3472	----	----
2ND DK NOTE 1	PASS (S) - ON DC DK	281	2904	----	----
3RD DK	GEN WORKSHOP, LAB, PASSAGE	1688	19060	800	23.8
3RD DK	LAUNDRY	302	3297	845	3.9
3RD DK	CHEM WARFARE DEF STRM	302	3297	75	44.0
3RD DK	CREW LIVING, TOILET, & SHR	734	7335	270	27.2

Table 3. (Continued)

DDG 51 CLASS

SMOKE CONTROL AREA	COMPARTMENTS	DK AREA (sq ft)	VOL (cu ft)	VENT AIR (cfm)	R/C (min)
03 LVL	AEGIS RDR, ARRAY RMS, ELEC LOAD CTR, ELEX WORKSHOP	2384	29204	[illegible]	57.3
01 LVL	BATT CHG & PALLET TRK STWG	224	2352	1040	2.3
1ST PL	FLAM LIQ STRM	133	1197	280	4.3
2ND PL	PWR SPLY CONVERSION RM	532	452[illegible]	75	60.3
1ST PL	PROV ISS RM, REFR MCHRY, PASSAGE, DRY PROV, SNAP 2 COMP RM	1170	10530	210	50.1
1ST PL	DEG PWR RM	112	1008	75	13.4
2ND PL	SPLY SPRT CTR, SD STRM	1851	15734	295	53.3
HOLD TO MN DK	AUX MCHRY RM	----	28075	11110	2.5
	MAIN ENGINE ROOM	----	59904	15125	4.0

EX-USS SHADWELL LSD 15

SMOKE CONTROL AREA	COMPARTMENTS	DK AREA (sq ft)	VOL (cu ft)	VENT AIR (cfm)	R/C (min) NOTE 2
3RD DK NOTE 1	AEGIS RDR, ARRAY RMS, ELEC LOAD CTR, ELEX WORKSHOP	1688	16880	195	86.6
3RD DK	BATT CHG & WORKSHOP (TYPICAL)	306	2831	235	12.0
3RD DK	FLAM LIQ STRM	306	2831	360	7.9
HOLD	PWR SPLY CONVERSION RM	1296	12960	160	81.0
HOLD	PROV ISS RM, REFR MCHRY, PASSAGE, DRY PROV, SNAP 2, COMP RM	668	6680	150	44.5
HOLD	DEG PWR RM	132	1320	75	17.6
HOLD	SPLY SPRT CTR, SD STRM	1592	15920	185	86.1
HOLD TO SS DK	MAIN MCHRY SPACE	----	42860	12500	3.4

NOTES

NOTE 1 Area provided with SATGCS damper.

NOTE 2 These vary from DDG 51 because of need to utilize 2 equal size TPSS for main zone; provide minimum 75 cfm terminal air quantity; and because vent air quantities are not volume dependent in all spaces.

BIBLIOGRAPHY

1 DTNSRDC Report SME-85/101, "Smoke and Toxic Gas Control System for Navy Ships", Carey, R., Feb 1986

2 DTNSRDC Report SME-86/111; "Smoke Ejection System for New Construction Ships - Equipment Heat Stress Evaluation Plan"; Brown, S., Carey, R.; Jan 1987.

3 DTNSRDC Report SME-87/16, "Smoke Management - A Test of the FFG 7 Class Smoke Removal Diagrams and Procedures on the USS CLIFTON SPRAGUE FFG 16"; Carey, R., Rodriguez, E.; (in preparation).

4 DTNSRDC Report SME-CR-14-86; "NAVSEA Smoke and Toxic Gas Program Reports A001, A002, A003, & A004 to T I GMI-133, Mod 1", Contract No. N00024-84-D-4487 with J.J. McMullen Associates, Inc.; Aug 1986.

5 NAVSEA Drawing SK-H-8563 (5 sheets), "FFG 7 Class Smoke Removal Diagram and Procedures"

6 "Full Scale Tests of Machinery Space Class B Fires and Ventilation System Configuration"; DiNenno, P.J., Hughes Associates, Dec 1986 (draft)

7 NAVSEA Drawing SK-H-8563 (5 sheets), "DDG 51 Class Smoke Removal Diagram and Procedures"

8 NAVSEA S9512-BS-MMA-010; "Heating, Ventilating and Air Conditioning Equipment Manual", Naval Sea Systems Command, Washington, D.C. 22202, 30 Sept 1985

9 "Shipboard Fire and Thermal Expansion Model", Contract No. N00167-84-D-0087, Delivery Order 0006, Task C, Engineering Computer Optecnomics, Inc.; Mar 1986.

10 NAVSEA 0901-LP-930-0003, Chapter 9930, "Firefighting-Ships", Sept 1986

11 NWP 62-1 (Rev A), "Surface Ship Damage Control".

12 "Smoke Control and Toxic Gas Removal for Staterooms and Laundry Spaces aboard Navy Ships", Engineering Computer Optecnomics, 1036 Cape St. Claire Center, Annapolis, MD, 21401 under DTNSRDC Contract N00600-80-D-D769(F021), Dec 1983

13 "Specifications for Smoke Ejection System HVAC Installation on LSD 15", J.J. McMullen Associates, Inc., Jan 1987

14 Westinghouse Electronic Corporation (MTD) "Smoke Removal Diagrams and Smoke Removal Procedures, Final", WMTD-5105049, Jan 1986.

15 "Addendum No. 1 to Air Conditioning, Ventilation and Heating Design Criteria Manual for Surface Ships of the United States Navy", NS 0938-018-0010; Oct 1980

16 "General Specifications for Ships of the United States Navy", NAVSHIPS 092-001-5000, 1986

END
9-87
DTIC